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The Effect of Concurrent Strength and Endurance Training on Electromechanical Delay, Maximum Voluntary Contraction, and Rate of Force Development

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Abstract

This study compared the effect of strength and endurance training and their combination on electromechanical delays (EMD), rate of force development (RFD) and maximum voluntary isometric contraction force (MVC) of the knee extensors in male and female subjects. The seven male and six female subjects were separated into a strength trained group (SG), 3 males and 3 females, and an endurance group (EG), 4 males and 3 females. The SG performed strength training solely with one leg and combined strength and endurance training with the other leg. The EG performed endurance training solely in one leg and combined strength and endurance training in the other leg. Strength training consisted of one legged work on a leg press weight machine. Endurance training consisted of one legged cycling on a cycle ergometer. EMD values were derived from electromyographic activity (EMG) recorded from the vastus lateralis muscle during MVC. MVC responses were made to a light stimulus and were performed with each leg, pre, mid and post training. MVC force was measured with a force transducer. Rate of force development (RFD) was determined from the MVC/time curves using computer software. The EMG, MVC/time curves and light signal data were simultaneously recorded on FM tape and later sampled at 2kHz and stored digitally. The results showed that EMD was significantly reduced only in the SG females. This change had occurred by mid evaluation. Post training data showed that the EMD values for the SG females had increased and were not different from initial levels. EMD times for the males were significantly shorter than the females. MVC for females significantly increased (approximately 40%) and were similar in both legs. The MVC of the males in EG showed significant and similar increases in both legs (approximately 20%). The MVC of the males in the SG showed no significant gains in either leg. Males were significantly stronger than females. Training did not increase RFD and RFD was greater in the males than the females. The data suggest that the increase in MVC that occurred with training in this study was not related to shorter EMD times.

Key words: Strength and endurance training, electromechanical delay, MVC, RFD

Introduction

Grabiner (1986) states that "every skeletal muscle contraction is preceded by an isometric phase referred to as the motor reaction time or electromechanical delay (EMD)". He further states that this EMD is defined as the elapsed time from muscle depolarization to onset of muscle force generation, and it is composed of chemical, electrical and mechanical events. The chemical and electrical events include the depolarization of the involved muscle fibers, the propagation of the action potential and the excitation-contraction coupling process. The mechanical events consist of the active generation of tension between the actin and myosin molecules, and the stretching of the elastic components associated with the shortening of the sarcomeres which leads to limb movement or increased tension (Grabiner, 1988). The time required for the mechanical events represents the major portion of the delay (Cavanagh and Komi, 1979; Grabiner, 1986). It has been shown that faster contractions produce shorter EMDs (Norman and Komi, 1979); that the EMD is shorter in males than females performing maximal voluntary isometric contractions (Bell and Jacobs, 1986); and that EMD tends to be shorter in stronger individuals than weaker individuals (Bell and Jacobs, 1986). Bell and Jacobs (1986) suggested that the shorter EMD during the maximal isometric contraction in males may be attributed to their greater strength and muscle mass. If shorter EMD is associated with greater strength and muscle mass then the question arises whether training which causes increases in strength and muscle mass also causes shortening of EMD. To test this hypothesis, measures of isometric strength, rate of force development and EMD were made before, mid and after 22 weeks of strength, endurance and combined strength and endurance training.

This paper describes one part of a multidiscipinary study which exaimed the interaction between concurrent strength and endurance training (Sale, 1987).

Method

Subjects:

Thirteen young healthy males and females volunteered for this study. Written informed consent was obtained from all subjects. None of the subjects had previously undergone any

extensive resistance or endurance training.

Groups:

The subjects were placed into two groups. One, a strength trained group (SG), 3 males and 3 females, performed strength training solely with one leg and combined endurance and strength training with the other leg. The second group was an endurance trained group (EG), 4 males and 3 females, which performed endurance training solely with one leg and combined strength and endurance training with the other. Physical characteristics of the groups are shown in Table 1.

Training:

The training exercise involved hip and knee extension and plantar flexion. The muscles were strength trained by performing unilateral leg presses on a weight stack leg press machine (Global Gym Inc., Downsview, Ontario). Six sets of 15-20 repetitions per training session were performed. The weight was progressively increased so that the last 2-3 sets were done to concentric contraction failure. Rest periods of 2 minutes intervened between sets. Endurance training consisted of five 3 minute bouts of unilateral cycle exercise performed at 90-100% unilateral cycle exercise $\dot{V}O_2$max. Three minute rest periods intervened between bouts. Training was performed 3 times per week for 6 months with a 3 week break mid training. This 3 week break occurred over the Christmas holidays when the subjects went home and training schedules could not be controlled. $\dot{V}O_2$max was measured for each leg separately and for both legs together. The test was performed on an electronically braked cycle ergometer using a standard continuous, progressive loading protocol. An open circuit computerized gas analysis system measured and displayed the heart rate, $\dot{V}E$,$\dot{V}O_2$,$\dot{V}CO_2$, and RER every 20 seconds.

Procedures:

The subjects were familiarized with training procedures a week prior to electromyographic muscle activity (EMG), maximum voluntary unilateral isometric contraction (MVC) and rate of

force development (RFD) measures. Muscle biopsies were obtained from the vastus lateralis of each leg pre, mid and post training and the data are documented elsewhere (Sale et al., unpublished results). During EMG and MVC testing the subjects were seated in a strength testing apparatus. An electromyography transducer was strapped over the week old incision scar on the vastus lateralis where the muscle biopsy had been taken. The silver-silver/chloride electrodes (bandwidth 10Hz-1kHz) were fixed in their rubber moulding at a distance of 3.5 cm from center to center, the diameter of each electrode being 1cm. The subjects performed 3 maximum MVC of the knee extensors against a strap which was attached to a force transducer. Contractions lasted no longer than 2 seconds. The analysis used the two most consistent and strongest contractions. The subjects contracted the muscles as quickly and strongly as possible after seeing a light stimulus. This would ensure that the shortest EMD would be produced. The MVCs were performed with the angle at the knee being maintained at approximately 110°. Two to three submaximal contractions were performed prior to the MVC. One minute rest intervals intervened between successive MVCs. The measurement of EMG, MVC and RFD were made pre, mid and post training.

Measurements:

An electromyography transducer, hybrid amplifier, and filter (Ampel model MV 9110-EMG) captured the EMG signal. This system then amplified the signal 1000 times. The signal was then full wave rectified and stored on FM Tape (HP model no. 3968A) at a speed of 3¾ inches per second. A strain gauge (Lebow model no. 3169) measured the force exerted by the subject. The signal from the force transducer was also recorded on FM tape along with the light stimulus signal. The tape was then taken back to the DCIEM laboratory. The light stimulus from the FM tape was then used to trigger the digital transient wave form recorders (Data Lab model no. DL2400), which sampled the EMG and force signals from the tape at 2000 samples per second. Computer software developed for the system determined the onset of EMG activity, the onset of force generation, the rate of force development (RFD) and the maximal force generated as describe previously (Bell and Jacobs, 1986). The onset of EMG

ctivity was defined as the point where rectified EMG continually exceeded the standardized EMG base line level. This level was produced as a result of applying a steady 49 newton force against the ankle strap before commencement of an MVC. The onset of force generation was defined as the first sample to exceed the standardized baseline force of 49N by 5N (Viitasalo et al., 1980). After the initial data reduction on the Deck 11/34 associated with the digital transient recorders, the data were transferred to a Vax 11/750 computer for statistical analysis.

Treatment of Data:

The data for each training group were analyzed separately with a 3 way analysis of variance design using BMDP software (Dixon, 1981). The design was as follows. For the strength grouping there were three independent variables, sex (male & female), training (strength trained & combined strength and endurance trained), and time (pre, mid and post). At each time period, 2 of the 3 measures on each leg were kept for the analysis. Thus making 6 measurements per cell i.e. 3 legs x 2 trials. The design for the endurance group was similar except that there were 4 legs in the male cell and 3 in the female cell. Where necessary a Duncan multiple range post-hoc test was used to determine differences among means.

Results

EMD

The analysis of variance of EMD for the SG showed that male EMD values were significantly shorter than their female counterparts ($p=.012$), EMD was the same in either leg regardless of the method of training ($p=.609$) and training appeared to have no effect on EMD ($p=.224$). There was, however, a training by sex interaction ($p=.011$). A post hoc analysis of this interaction revealed that the male EMD values were similar across trials while the mid values for the females were significantly shorter than pre values ($p<.05$).

The analysis of variance for EMD for the EG showed that male EMD values were again shorter than female values ($p=.039$), EMD was the same in either leg regardless of the method

of training (p=.794) and training had no effect on EMD (p=.125). Figure 1 shows the EMD mean values of the SG and EG after pooling the data for both legs.

MVC

The analysis of variance for the SG showed that the males were significantly stronger than the females (p=.0004), that strength may have improved with training (p=.051) and that similar changes occurred in both legs regardless of the method of training (p=.915). A post hoc analysis of the training duration and sex factors revealed that only the MVC for the females increased significantly over time and this change occurred after 22 weeks of training.

The analysis of variance for the MVC for the EG showed the males were significantly stronger than the females (p=.0004), MVC significantly increased with training (p=.0004) and similar changes occurred in both legs regardless of the method of training (p=.547). A post hoc analysis of the time and sex factors revealed that the MVC for the males in the Endurance group significantly increased after 22 weeks of training. The MVC of the females of this group significantly increased after 11 weeks of training and showed no further significant increases post training.

Figure 2 shows the means of the MVC of the SG and the EG group after pooling the data for both legs.

RFD

The analysis of variance of RFD for the SG revealed that the RFD from 25-50% and 50-75% MVC for the males was significantly greater than the values for the females, p=.0004 and p=.0004 respectively; that RFD was the same in either leg regardless of the method of training, p=.726 and p=.660 respectively; and training did not increase RFD, p=.863 and p=.733 respectively. The analysis of variance for RFD from 75-100% MVC showed that the RFD values for the males and females were similar, p=.109, that RFD was the same in either leg regardless of the type of training, p=.773, and training had no effect on RFD, p=.065. The RFD for the males and the females pre mid and post training in the SG from 25-50%, 50-75%

and 75-100% MVC are given in Table 2 after pooling the data for both legs.

The analyis of variance of RFD for the EG revealed that the RFD from 25-50% and 50-75% MVC for the males was significantly greater than the values for the females, p=.033 and p=.0002 respectively; that the RFD was the same in either leg regardless of the method of training, p=.994 and p=.869 respectively; that training did not increase RFD from 25-50% MVC, p=.982, but RFD did increase from 50-75% MVC p=.037 but only in the males. The analysis of variance of RFD from 75-100% MVC showed that the RFD for the males and females were similar, p=.287; that the method of training had no effect on RFD, p=.177, and training did not effect the RFD p=.801. The RFD for the males and the females pre, mid and post training in the EG from 25-50%, 50-75% and 75-100% MVC are given in Table 3, after pooling the data of both legs for the training methods.

Discussion

EMD

It was anticipated that EMD would decrease if MVC and/or muscle mass increased with training. In the present report, training appeared to have little effect on EMD despite a significant increase in MVC which occurred in this study and muscle mass documented elsewhere by Sale et al. (unpublished results) in both the SG and EG seen post training. The results suggest that the observed sex difference in EMD may not be simply related to increased MVC or differences in muscle mass.

EMD has been shown to be muscle fiber dependent (Brody, 1976; Grabiner, 1986; Norman and Komi, 1979) and related to the RFD (Komi, 1984; Viitasalo and Komi, 1981). EMD was associated with RFD in this study producing moderate but significant ($p<.05$) correlations of -0.431 and -0.445 for RFD between 25-50 and 50-75% MVC. Komi (1984) has suggested that the lower RFD he observed in females compared to males may be a result of structural differences in the muscle's elastic tissue. It is tempting to speculate that if such differences exist it could be reflected in the different EMD values between males and females

found in this and the study of Bell and Jacobs (1986). In both studies the females had lower RFD's than the males.

Belanger and McComas (1981) have shown that during MVC manoeuvres some individuals cannot completely activate all the available motor units. An inability to recruit the available units would not only decrease maximum force but also result in a longer EMD provided it was the fast twitch units that are left unrecruited (Viitasalo and Komi, 1981). It is possible that a neural component as suggested by Moritani and De Vries (1979) may be responsible for the initial strength gains in MVC observed mid training in the SG females, and that the neural component may also be resposible for the reduced EMD. The females may have 'learned' to recruit and synchronize the firing of the fast twitch motor units. Thus producing an increased MVC and smaller EMD without an increase in muscle mass. With the continuation of training, MVC increased significantly and muscle hypertrophy occurred. EMD, however, was not reduced further, nor was it maintained. It return towards pre training levels. Thus it may be the neural component of strength, ie motor unit recruitment and synchronization, which affects EMD and not the increased MVC and/or muscle mass as initially proposed. Such a hypothesis might help to explain the results of the SG male subjects. They did not experience the same magnitude of change in MVC and EMD mid training as did the females. This suggests that the males' ability to recruit and synchronize motor unit firing of the fast twitch fibers had been developed previously. Milner-Brown et al. (1975) have shown that synchronization of motor units is associated with specific neural pathways and appears to be training related. In addition synchronization is more prominent in the fast twitch fibers (Milner-Brown et al., 1975). Better recruitment and synchronization of the motor units by the males may be the reason for the observed differences in EMD between males and females and this mechanism could be an alternative to the structural differences in muscle elasticity suggested by Komi (1984).

MVC

All groups showed significant improvements in MVC when strength training occurred

separately or in combination with endurance training, except for the SG males. The lack of improvement in MVC for the males and the delayed improvement seen for the females of the SG may be a result of their relatively high initial strength level (see Figure 2). The males and females of the SG were respectively 19 and 25% stronger than the males and the females of the EG. A further analysis of the initial MVC values showed the SG to be significantly stronger ($p=.003$) than the EG and it is well known that when less fit individuals begin strength training improvements occur earlier and are usually greater (Hakkinen, 1985, Hakkinen and Komi, 1981). The delay in strength improvement may, therefore, be partially attributed to initial strength levels.

Another possible confounding factor accounting for the lack of improvement in the SG males may be the method of testing employed for measuring strength increases. The subjects trained dynamically on a leg press training apparatus but were tested isometrically for MVC. Dons et al. (1979) have pointed to similar findings where isometric MVC has not improved in spite of dynamic strength improvements of the same muscle group when training was performed dynamically. This points to a specificity of training factor which in conjunction with the initially higher MVC of the SG males, may accounts for the lack of significant increase.

There may also be another contributing factor to the retarded or delayed improvements in the SG. After the initial 11 weeks of training no significant increases had occurred in either the males or the females of this group. Usually in strength taining studies of similar duration strength is increased and the increases are attributted to both neural factors (Hakkinen and Komi, 1981; Houston et al., 1983; Jacobs and Abramavicius, 1985; Moritani and DeVries, 1979) and muscle hypertrophy (Hakkinen and Komi, 1981; Luthi et al., 1986; Moritani and DeVries, 1979; Thorstensson et al., 1976). Hickson (1980), however, using a two group model showed that concurrent strength and endurance training impedes strength gains at the upper levels of strength development. In the present model we may have complicated things even further because we did not functionally separated the neural drive to the legs. Coincident with

this we did not see the strength improvement Hickson (1980) did over the first 11 weeks of training. Moreover, if the responses to training of the sexes in the SG are compared to the responses of the corresponding sexs in the EG, improvements in strength are delayed or retarded for the SG. In addition the unpublished results of Sale et al. for the present subjects showed that the SG increases in muscle mass were smaller than the EG, 12% vs 17% respectively. These facts tend to suggest that perhaps a more severe impairment occurs in the present model, that the neural respones of combined training and strength training may be interfering with each other and thus hampering cellular adaptation. McDonagh and Davies (1984) tend to support this conjecture by stating that 'in order to produce fiber hypertrophy neural impulse traffic must be preserved'.

The percent change in MVC found in this study ranged from 6.4% to 20.2% for the SG and EG males, respectively, and from 37.7% to 57.1% for the SG and EG females, respectively. These changes are similiar to other training studies reorted in the literature (Gettman et al., 1980; Hakkinen and Komi, 1983; Komi, 1986; Luthi et al., 1986; Mortani and DeVries, 191979; Thorstensson et al., 1976).

RFD

RFD did not increase with training in this study, except for the EG males and this increase was only for the 50-75% post training. The lack of change in RFD should have been expected based on previous studies which have shown that different types of strength training affect RFD differently (Hakkinen et al., 1986; Hakkinen et al., 1985; Hakkinen et al., 1984; Viitasalo and Komi, 1978). Hakkinen et al. (1985) have shown that explosive strength training will increase RFD. The same authors have also shown that the RFD in weight-trained individuals is less than the RFD in wrestlers or body builders and attributes the difference to the type of training (Hakkinen et al., 1984). Thus, it appears that specificity of training plays an important role in RFD gains.

The lack of change in RFD with training as seen in this study may also be a factor accounting for the lack of change in EMD values as both Bell and Jacobs (1986) and Viitasalo

and Komi (1981) and Komi (1984) have shown associations between RFD and EMD.

Conclusion

As this was a smaller side project connected with a main study (Sale, 1987), the model used complicates the interpretation of the data. It appears that one can not completely isolate the the neural, metabolic and perhaps the hormonal effect of training to a particular leg. Except for the strength trained males who showed no increase in isometric MVC post training, all other leg groups showed increases in strength and shorter EMDs after the initial 11 weeks. The EMD changes, however, were only significant for the SG females. The EMD changes also tended to precede strength increases, however, these changes were not increased or even maintained after a further 11 weeks of training. This suggested that the EMD change seen mid training may be more neurally related rather than related to increased strength and muscle mass as initially hypothesised. It is also suggested that the ability to recruit and synchronize the fast twitch fibers may be the mechanism behind the shorter EMDs found in males.

The present results confirm the sex difference in EMD reported earlier by Bell and Jacobs (1986).

The results also indicate that dynamic strength training caused a significant improvement in isometric MVC, and that in general RFD did not change with training.

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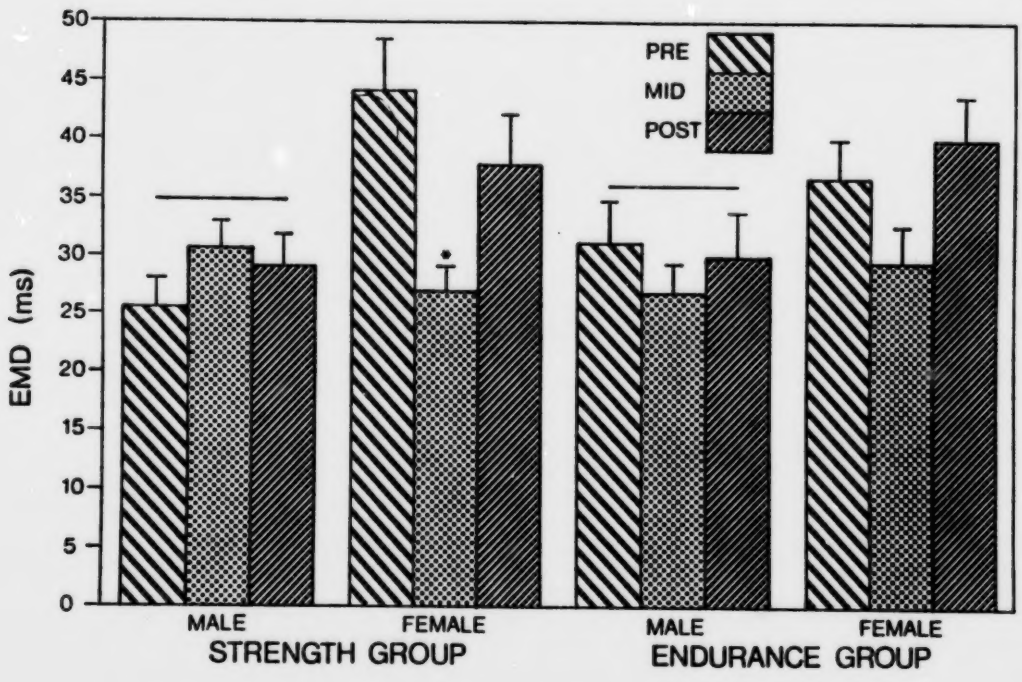
Figure 1: A comparison of the electro-mechanical delay pre, mid and post strength and endurance training.



* Significantly different from pre values $p < .05$
Significantly different from female values $p < .05$
Values are mean ± standard error

Figure 2: A comparison of the maximum voluntary isometric contraction of the knee extensors pre, mid and post strength and endurance training.

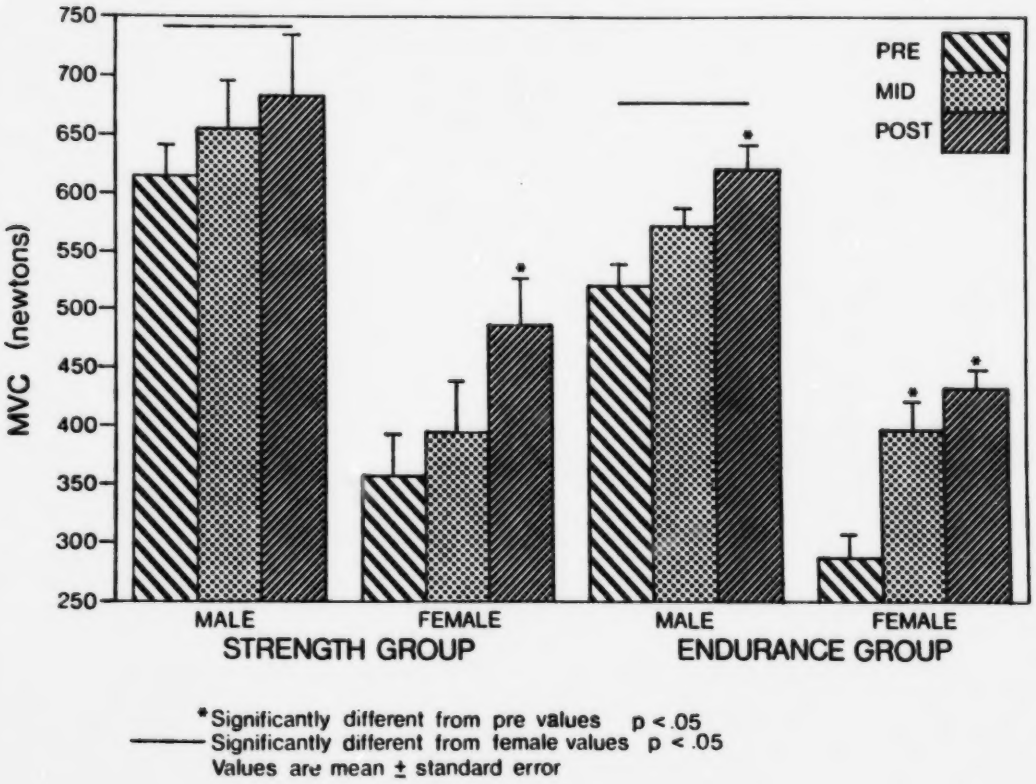


Table 1. Group Physical Characteristics

	Strength Group		Endurance Group	
	Males	Females	Males	Females
Age (yrs)	21.3 ±2.3	20.3 ±0.6	20.3 ±0.5	21.3 ±1.2
Height (cm)	179.5 ±7.8	160.9 ±9.6	171.7 ±6.3	161.7 ±1.5
Weight (kg)	77.7 ±6.8	54.5 ±2.5	71.0 ±6.2	54.3 ±2.6
n	3	3	4	3

Values are mean ± standard deviation.

Table 2.

Rate of Force Development between 25-50, 50-75, and 75-100% of an Isometric MVC of the Knee extensors Strength Group

	pre		mid		post	
	males	females	males	females	males	females
RFD						
25-50%	4.34	2.03*	3.96	2.06*	3.93	2.39*
($N.ms^{-1}$)	±1.60	±1.18	±1.00	±1.00	±0.90	±0.99
50-75%	2.71	1.65*	2.70	1.56*	2.81	1.80*
($N.ms^{-1}$)	±0.60	±0.95	±0.71	±0.77	±0.40	±0.69
75-100%	0.90	0.64	0.88	0.50	0.39	0.45
($N.ms^{-1}$)	±0.76	±0.51	±0.50	±0.33	±0.25	±0.26

* Males and females are significantly different at $p < .05$.

Values are means ± standard deviation.

Table 3.

Rate of Force Development between 25-50, 50-75, and 75-100% of an Isometric MVC of the Knee extensors for Endurance Group

	pre		mid		post	
	males	females	males	females	males	females
RFD						
25-50%	3.03	2.68*	3.21	2.48*	3.20	2.60*
($N.ms^{-1}$)	±1.03	±1.17	±1.12	±1.40	±0.74	±1.35
50-75%	1.81	1.44*	2.09	1.51*	2.32†	1.76*
($N.ms^{-1}$)	±0.60	±0.57	±0.67	±0.63	±0.38	±0.57
75-100%	0.70	0.46	0.70	0.59	0.56	0.63
($N.ms^{-1}$)	±0.42	±0.37	±0.31	±0.45	±0.25	±0.53

* Males and females are significantly different at $p<.05$.

† Significantly different from pre value at $p<.05$

Values are means ± standard deviation.

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The Effect of Concurrent Strength and Endurance Training on Electromechanical Delay, Maximum Voluntary Contraction, and Rate of Force Development

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This study compared the effect of strength and endurance training and their combination on electromechanical delay (EMD), rate of force development (RFD) and maximum voluntary contraction force in male and female subjects. Two training groups, a strength group (SG 6 subjects) and an endurance group (EG, 7 subjects) were formed. The SG performed strenth training with one leg while combining strength and endurance training with the other. The EG performed endurance training with one leg while combining strength and endurance with the other.The hypothesized reduction in EMD with increased muscle mass cr strenth as a result of strength training did not occur. The authors suggest from the data a new hypothesis that shorter EMD values observed in stronger individuals are not related to strength pre se but to muscle fiber recruitment.

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Strength and endurance training, electromechanical delay, MVC, RFD